

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Commissioner
 US Department of Commerce
 United States Patent and Trademark
 Office, PCT
 2011 South Clark Place Room
 CP2/5C24
 Arlington, VA 22202
 ETATS-UNIS D'AMERIQUE
 in its capacity as elected Office

Date of mailing (day/month/year) 02 November 2000 (02.11.00)	
International application No. PCT/GB00/00566	Applicant's or agent's file reference MPS/7133INT
International filing date (day/month/year) 17 February 2000 (17.02.00)	Priority date (day/month/year) 18 February 1999 (18.02.99)
Applicant SUGDEN, Catherine, Anne et al	

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:
 12 September 2000 (12.09.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer Juan Cruz Telephone No.: (41-22) 338.83.38
---	---

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference MPS/7133INT	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/00566	International filing date (day/month/year) 17/02/2000	Priority date (day/month/year) 18/02/1999
International Patent Classification (IPC) or national classification and IPC G01L1/24		
Applicant OXFORD FIBER OPTIC TOOLS LIMITED et al.		



1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 6 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

 These annexes consist of a total of 10 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 12/09/2000	Date of completion of this report 07.05.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Coda, R Telephone No. +49 89 2399 2802 

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/GB00/00566

I. Basis of the report

1. With regard to the **elements** of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17):*

Description, pages:

2,3,5-11	as originally filed	
1,4,12	with telefax of	23/02/2001

Claims, No.:

1-17,18 (part),25 (part),	with telefax of	23/02/2001
26-52		
18 (part),19-24, 25 (part)	with telefax of	26/02/2001

Drawings, sheets:

1/2,2/2	as originally filed
---------	---------------------

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/GB00/00566

- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
☐ the claims, Nos.:
☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

- ☐ the entire international application.
☒ claims Nos. 52.

because:

- ☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):
- ☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 52 are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet
- ☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.
- ☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

- ☐ the written form has not been furnished or does not comply with the standard.
☐ the computer readable form has not been furnished or does not comply with the standard.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00566

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1 - 51
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1 - 51
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1 - 51
	No:	Claims	

2. Citations and explanations see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Re Item III

Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

Contrary to the requirements of Rule 6.2(a) PCT, claim 52 relies on reference to the drawings.

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. **Technical Field**

Fibre optic grating sensors.

2. **Novelty (Art. 33(2) PCT)**

None of the cited documents discloses a periodical variation of the refractive index which is substantially continuous to form an at least substantially continuous grating structure, therefore the subject-matter of claims 1 and 25 is novel (Article 33(2) PCT).

3. **Inventive Step (Art. 33(3) PCT)**

The document D2 (WO 96 24079 A) represents the closest prior art.

This document discloses a fibre optic grating sensor with an optical fibre having a grating portion along which the refractive index of the fibre varies periodically.

The claim 1 is distinguished in that the periodical variation of the refractive index is substantially continuous to form an at least substantially continuous grating structure, the periodic variation having an amplitude envelope which includes at least one region in which the amplitude of the envelope is substantially reduced, the variation giving the grating portion a spectral profile within which there is at least one pass band.

The problem to be solved by the present invention may therefore be regarded as how to provide a fibre optic grating sensor with improved spatial and spectral resolution. The other documents cited in the search report are less relevant: the document D1 (EP-A-0 893 712) discloses a band pass filter which cannot readily be used as a sensor, both documents D3 (US-A-5 706 079) and D4 (EP-A-0 897 124) disclose

fibre gratings without any reduction of the amplitude of the envelope.

Since none of the cited documents hints at including grating regions in which the amplitude of the envelope is substantially reduced and a pass band is defined, causing the advantage of reducing the sensor length and allowing quasi-point measurements, increasing then the spatial and spectral resolution of the sensor, claim 1 meets therefore the requirements of inventive step referred to in Art. 33(3) PCT.

It is also noted that none of the cited documents hints at including a grating section in which the phase of the periodic variation of the refractive index reverses, as defined in the independent claim 25. Therefore, also the independent claim 25 meets the requirements of inventive step referred to in Art. 33(3) PCT.

4. Industrial Applicability

Without any doubts the application as defined in claims 1 to 51 is industrially applicable.

5. Dependent Claims

Claims 2 to 51 are dependent on either claim 1 or claim 25 and as such also meet the requirements of the PCT with respect to novelty and inventive step.

Re Item VII

Certain defects in the international application

It is observed, that the independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT, the reference signs are missing, Rule 6.2(b) PCT and neither the relevant background art has been acknowledged in the description nor the document D2 (WO 96 24079 A) has been cited, Rule 5.1(a)(ii) PCT.

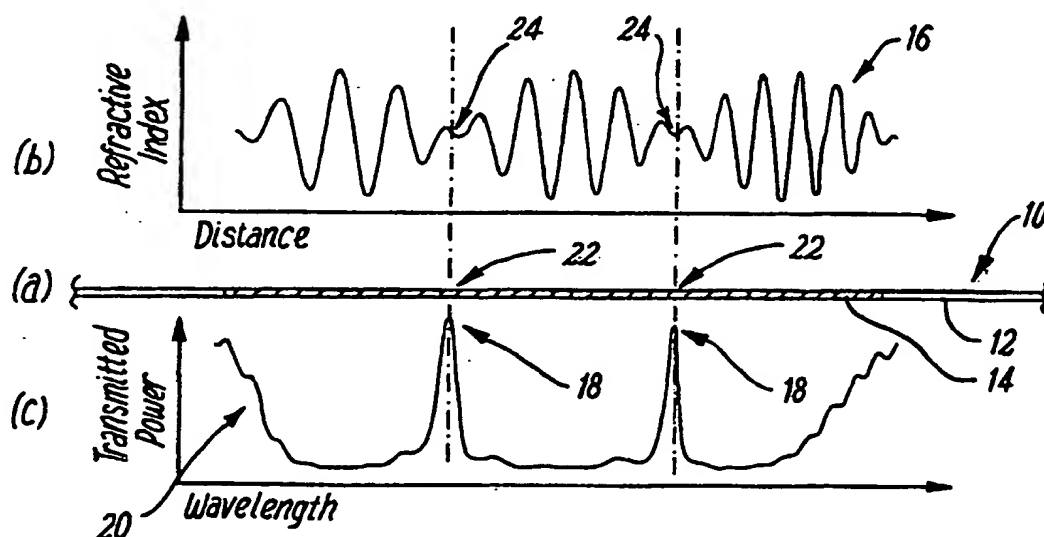
These minor defects could be addressed in the respective national or regional phases of the examination.



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G01L 1/24, G02B 6/34, G01B 11/16		A1	(11) International Publication Number: WO 00/49378
			(43) International Publication Date: 24 August 2000 (24.08.00)
(21) International Application Number: PCT/GB00/00566		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 17 February 2000 (17.02.00)		<p>Published With international search report.</p>	
(30) Priority Data: 9903597.4 18 February 1999 (18.02.99) GB			
(71) Applicant (for all designated States except US): OXFORD FIBER OPTIC TOOLS LIMITED [GB/GB]; Aston Science Park, Love Lane, Birmingham B7 4BJ (GB).			
(72) Inventors; and (75) Inventors/Applicants (for US only): SUGDEN, Catherine, Anne [GB/GB]; Oxford Fiber Optic Tools, Aston Science Park, Love Lane, Birmingham B7 4BJ (GB). CHISHOLM, Karen, Elizabeth [GB/GB]; Oxford Fiber Optic Tools Limited, Aston Science Park, Love Lane, Birmingham B7 4BJ (GB). ZHANG, Lin [CN/GB]; Electronic Engineering, Aston University, Aston Triangle, Birmingham B4 7ET (GB).			
(74) Agent: SKINNER, Michael, Paul; Swindell & Pearson, 48 Friar Gate, Derby DE1 1GY (GB).			

(54) Title: FIBRE OPTIC GRATING SENSOR



(57) Abstract

A fibre optic grating sensor (10) comprising an optical fibre (12) in which a grating portion (14) is provided, the refractive index (16) of the fibre (12) varying periodically along the grating portion (14). The periodic variation of the refractive index (16) has an amplitude envelope which includes, in this example, two regions (24) in which the amplitude of the envelope is substantially reduced, and in this example is substantially nulled. The null regions (24) give the grating portion a spectral profile (20) within which there are, in this example, two pass bands (18).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Fibre Optic Grating Sensor

This invention relates to a fibre optic grating sensor, particularly but not exclusively a fibre optic grating strain or temperature sensor.

It is known that fibre Bragg gratings may be used as a tool for measuring, for example, temperature and strain. The grating is formed in the fibre to reflect light at a wavelength which is determined by the physical characteristics of the grating. A change in the temperature and/or strain applied to a fibre Bragg grating changes the period of the grating and hence the wavelength of the light reflected by the grating. Arrays of fibre Bragg gratings, in which the gratings are spatially separated along a length of fibre and the spectral profiles of the gratings are separated in wavelength, have been used to measure strain and temperature gradients by illuminating the array with broadband light and measuring the wavelength of the reflected light. A measurement of the wavelength shift (if any) provided by each grating provides information about the strain or temperature at that grating. Using a grating array to make a quasi-distributed strain or temperature measurement along a short length (about 5cm or less) requires the fabrication of grating arrays comprising gratings of very short spatial length (generally less than 4mm). For short length arrays, the spatial separation between adjacent gratings often becomes comparable to the spatial length of the gratings. In order to increase the number of gratings within the array the length of the gratings must be decreased, which rapidly increases the spectral bandwidth of the grating and hence reduces the spectral resolution of the sensor.

It is an object of the present invention to provide an improved fibre optic grating sensor.

According to one aspect of the present invention there is provided a fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation having an amplitude envelope which includes at least one region in which the

amplitude of the envelope is substantially reduced, the said variation giving the grating portion a spectral profile within which there is at least one pass band.

Preferably, the amplitude envelope includes at least one region in which the amplitude of the envelope is substantially nulled. The amplitude envelope preferably includes a plurality of regions in which the amplitude of the envelope is substantially nulled. Each null region desirably gives rise to a corresponding pass band.

Preferably, the periodic variation in the or each region includes a section in which the phase of the periodic variation substantially reverses, the or each reduction in the amplitude of the refractive index envelope and the or each corresponding phase reversal acting to give rise to a corresponding pass band within the spectral profile of the grating portion.

Adjacent null regions and hence adjacent sensor elements, are desirably spatially separated. Preferably each sensor element is independently actuatable and hence the wavelengths of the corresponding pass bands are independently variable.

The grating portion preferably comprises two substantially superimposed fibre Bragg gratings. The amplitudes of the refractive index profiles of the two gratings preferably add together to form the amplitude envelope and the or each phase change.

The fibre Bragg gratings are preferably chirped fibre Bragg gratings. Desirably, the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the second chirped grating. Alternatively, the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.

Alternatively, the fibre Bragg gratings may be linear fibre Bragg gratings. The two linear gratings preferably have substantially the same spectral bandwidth. Desirably the first linear grating has a different central wavelength to the second linear grating.

The grating portion may alternatively comprise one fibre Bragg grating having a plurality of regions within which the refractive index profile of the grating is substantially reduced or nulled.

The fibre Bragg gratings are preferably fabricated using a known two-beam interference holographic fabrication method. Alternatively, the fibre Bragg gratings may be fabricated using a known phase-mask fabrication method.

The null regions in the single fibre Bragg grating are desirably formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method by providing an amplitude mask generally in front of the fibre, generally in the beam paths, during fabrication. Alternatively, the null regions in the single fibre Bragg grating may be formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method or the phase-mask fabrication method by subsequently further exposing regions of the grating. The single fibre Bragg grating may be a linear grating or a chirped grating.

The grating portion may further alternatively comprise a single grating structure fabricated using the phase-mask fabrication method. The desired grating structure is preferably represented on a phase-mask and subsequently inscribed into the fibre through the phase-mask. Alternatively, the grating structure may be inscribed in the fibre through a phase-mask, the fibre undergoing oscillating motion, along its longitudinal direction, relative to the phase-mask to thereby control the refractive index profile within the grating structure. The phase-mask may alternatively or additionally undergo oscillating motion relative to the fibre.

According to a further aspect of the present invention there is provided a fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation including at least one section in which the phase of the periodic variation substantially reverses, the said variation giving the grating portion a spectral profile within which there is at least one pass band.

The grating portion preferably includes a plurality of sections in which the phase of the periodic variation substantially reverses. The or each phase reversal section desirably gives rise to a corresponding pass band. Adjacent phase reversal sections, and hence adjacent sensors, are desirably spatially separated. Preferably each sensor is independently actuatable and hence the wavelengths of the corresponding pass bands are independently variable.

Preferably, the period of the periodic variation changes along at least part of the grating portion, and most preferably changes along substantially the full length of the grating portion.

The grating portion preferably comprises two substantially overlapping chirped fibre Bragg gratings, the first chirped grating being spatially shifted relative to the second chirped grating by an integer plus a fraction of the period of the first grating. The first chirped grating is preferably spatially shifted relative to the second chirped grating by an integer plus one half of the period of the first grating.

Desirably, the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the second chirped grating. Alternatively, the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.

The fibre Bragg gratings are preferably fabricated using a known two beam interference holographic fabrication method. Alternatively, the fibre Bragg gratings may be fabricated using a known phase-mask fabrication method.

Alternatively, the grating portion may comprise one chirped fibre Bragg grating having a plurality of sections in which the phase of the periodic variation substantially reverses.

The single chirped fibre Bragg grating is preferably fabricated using a known phase-mask fabrication technique. Preferably, a first part of the chirped grating having a first spectral bandwidth is represented on a phase-mask and subsequently inscribed into the fibre. A second part of the chirped grating having a second spectral bandwidth is preferably inscribed into the fibre substantially spatially and spectrally adjacent the first part, the first and second parts together forming the chirped grating. Preferably, the chirped grating comprises a plurality of such parts arranged substantially spatially and spectrally sequentially adjacent one another.

Preferably, the fibre is under a first strain during inscription of the first part. The fibre is preferably under a second strain during subscription of the second part, the first and second strains being different.

The chirped grating may alternatively be fabricated using a single phase-mask, the desired structure of the chirped grating being represented on the phase-mask and subsequently inscribed into the fibre through the phase-mask.

The chirped grating may further alternatively be fabricated using a known continuous writing technique.

The optical fibre is preferably photosensitive enhanced optical fibre. The photosensitive enhanced optical fibre may be germania doped optical fibre, or boron-germania co-doped optical fibre. The germania doped fibre may be

hydrogen loaded to further increase the photosensitivity of the fibre. The boron-germania co-doped fibre may be hydrogen loaded to further increase the photosensitivity of the fibre. The photosensitive enhanced optical fibre may alternatively be hydrogen loaded standard optical fibre. The hydrogen loaded fibre may be annealed following fabrication of the grating structure to substantially remove any residual hydrogen from the fibre.

The grating structure may further alternatively comprise a side-etched surface-relief grating structure, preferably fabricated in standard optical fibre.

The fibre grating sensor may comprise a plurality of grating portions.

A specific embodiment of the invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Figure 1(a) is a diagrammatic representation of a fibre optic grating sensor according to the present invention, comprising a Moiré grating;

Figure 1(b) is a diagrammatic representation of the theoretical refractive index profile of the Moiré grating of figure 1(a);

Figure 1(c) is a diagrammatic representation of the theoretical spectral profile of the Moiré grating of figures 1 (a) and (b);

Figure 2 shows the optical spectrum of a 10-pass band Moiré grating constructed according to the invention;

Figure 3 shows linear-strain-gradient measurements taken using the grating of figure 2; and

Figure 4 shows exponential-temperature-gradient measurements taken using an 8-pass band Moiré grating constructed according to the invention.

Referring to the drawings, there is provided a fibre optic grating sensor 10 comprising an optical fibre 12 in which a grating portion 14 is provided, the refractive index 16 of the fibre 12 varying periodically along the grating portion 14. The periodic variation of the refractive index 16 has an amplitude envelope which includes, in this example, two regions 24 in which the amplitude of the

envelope is substantially reduced, and in this example is substantially nulled. The null regions 24 give the grating portion a spectral profile 20 within which there are, in this example, two pass bands 18.

While it is preferred that the amplitude envelope includes regions 24 in which the amplitude of the envelope is substantially nulled, it is sufficient that the amplitude of the envelope is merely significantly reduced. That is to say, the amplitude of the envelope must be sufficiently reduced to give rise to identifiable, and measurable, pass bands 18 within the spectral profile 20 of the grating portion 14. The pass bands 18 are required to be identifiable one from the other, and from any light present at other wavelengths.

In this example, the grating portion is a Moiré grating formed by the notional or actual superimposition of two Bragg gratings. Each Bragg grating is "chirped". That is, the period of the grating changes along its length, either in linear fashion, or in a more complex manner. The wavelength reflected by a chirped-period, or "chirped" grating will vary along the length of the grating. The variation will be linear in the case of linear chirp, and more complex in other cases. By contrast, a linear grating reflects substantially the same wavelength along the length of the grating. A chirped grating has a broader spectral bandwidth than a linear grating of the same length.

The Moiré grating 14 is fabricated using a known two-beam interference holographic fibre grating fabrication method. Two chirped-period fibre Bragg gratings are inscribed in the same section of fibre 12 by two sequential inscribing operations. The two chirped gratings are of substantially the same physical length and have substantially the same spectral bandwidth. However, the central wavelength of the first chirped grating is slightly shifted in wavelength relative to the central wavelength of the second chirped grating. The amplitudes of the refractive index profiles of the two superimposed chirped gratings add together to produce the refractive index profile 16 of the Moiré grating 14 and thereby form the amplitude envelope of the refractive index profile 16 along the fibre.

Figure 1 illustrates how the refractive index profile 16 of a chirped Moiré grating 14 gives rise to pass bands 18 within the bandwidth of the spectral profile 20 of the Moiré grating 14, and to sensors 22 within the core of the optical fibre 12. In the regions within the amplitude envelope where nulls 24 occur, the grating strength is nulled. Where the grating strength is nulled no light is reflected by that region of the grating 14, and hence pass bands 18 are created.

The regions within the fibre core where the nulls 24 in the amplitude envelope, and in the grating strength, occur may act as sensors 22. The length of a sensor 22 is the length within the fibre core in which the grating strength is substantially reduced or nulled. The spectral profiles of the sensors 22 are therefore the spectral profiles of the pass bands 18. The spectral bandwidth of the pass bands 18 is determined by the strength and chirp-rate of the Bragg gratings which form the Moiré grating 14.

The exact position of each sensor 22 can be calculated from the spectral profile 20 of the Moiré grating 14, knowing the exact length of the Moiré grating 14 and the manner in which the grating is chirped. The approximate length of each sensor 22 can be calculated using the full width half maximum spectral bandwidth of the pass bands 18.

Each sensor 22 occurs at a respective position in wavelength space and is independently actuatable. Consequently each pass band 18 is independently variable in wavelength, within the bandwidth of the spectral profile 20 of the Moiré grating 14, in accordance with the value of the parameter being measured at the site of the corresponding sensor 22.

Figure 2 shows the spectral profile 30 of a chirped Moiré grating which comprises 10 pass bands 32. The Moiré grating was fabricated using the two-beam interference holographic method. A frequency doubled Argon Ion laser of wavelength 244nm was used and the Moiré grating was fabricated in hydrogen loaded germania doped optical fibre, such as that manufactured by Spectran. A

first chirped fibre Bragg grating was fabricated having approximately 70% reflectivity, then a second chirped fibre Bragg grating of slightly different central wavelength was inscribed in the same piece of fibre. The wavelength shift between the two chirped gratings is 2nm. The magnitude of the wavelength shift determines the number of pass bands 32 in the Moiré grating.

The length of the Moiré grating of Figure 2 is approximately 6mm. The total spectral bandwidth is 12.6nm. The average bandwidth of the pass bands 32 is 0.39nm and the finesse is approximately 2.5. The approximate sensor length is less than 200 μ m.

Figure 3 shows strain measurement results taken using the 10 peak Moiré grating of figure 2. The measurements show how the strain varies along the length of the Moiré grating. The Moiré grating was bonded into grooves on a piece of spring steel (not shown). The steel was bent using a 4-point bending rig in order to effect a linear strain gradient along the Moiré grating. Figure 3 shows the strain measurements taken using the Moiré grating with the steel plate bent by three different amounts, to produce three different strain gradients.

The wavelengths of the pass bands 32 were measured in transmission using a tuneable laser and optical spectrum analyser, giving a measurement resolution of 0.01nm. The light from the tuneable laser was launched into a fibre grating sensor 10 comprising the 10 pass band Moiré grating and light transmitted by the Moiré grating was detected and measured using the optical spectrum analyser. The wavelength of the tuneable laser was tuned across the spectral bandwidth of the Moiré grating in order to interrogate in turn the sensor corresponding to each pass band 32.

The change in the central or peak wavelengths of the pass bands 32, between the unstrained starting state and the strained states, is calculated. The equivalent axial strain on each sensor is then calculated from the fractional

change in the central wavelength (λ_B) of the corresponding pass band 32 of each sensor, using:

$$\Delta\lambda_B/\lambda_B = (1-p_e) \varepsilon$$

where p_e is the effective photosilicate constant, which is 0.22 for germanosilicate fibre, and ε is the applied axial strain.

The measurements 34 recorded for the steel plate bent by a first amount indicated that a linear strain gradient of $12.1\mu\varepsilon/\text{mm}$ was present across the Moiré grating. The measurements 36 recorded for the steel plate bent by a second amount indicated that a linear strain gradient of $23.4\mu\varepsilon/\text{mm}$ was present across the Moiré grating. The measurements 38 recorded for the steel plate bent by a third amount indicated that a linear strain gradient of $38.2\mu\varepsilon/\text{mm}$ was present across the Moiré grating.

The measurements recorded using this 10 pass band Moiré grating have a strain resolution of $8\mu\varepsilon$ and a spatial resolution of approximately $450\mu\text{m}$.

Figure 4 shows exponential temperature gradient measurements taken using a 8 pass band Moiré grating. The grating was fabricated using the two-beam interference holographic method, as described above. The spectral bandwidth of the Moiré grating is 12.8nm and the wavelength shift between the two chirped gratings is 2.5nm . The measurements show how the temperature varies along the length of the Moiré grating. One end of the Moiré grating was bonded horizontally to a hot plate, to provide an exponentially decaying temperature gradient with distance away from the hot plate, and along the Moiré grating.

The Moiré grating was interrogated generally as described above, using broadband Erbium fluorescence source and an optical spectrum analyser, giving a measurement resolution of 0.08nm which corresponds to a temperature resolution of approximately 6°C . The change in the central wavelength (λ_B) is

calculated for each pass band. The equivalent axial temperature is then calculated using:

$$\Delta\lambda_B/\lambda_B = (a + \xi)\Delta T$$

where a is the thermal expansion co-efficient of the optical fibre (0.55×10^{-6} for fused silica), ξ is the thermo-optic coefficient (approximately 8.3×10^{-6} for germania-doped silica) and ΔT is the applied temperature change.

By way of comparison, a linear fibre Bragg grating of the same length (200 μm), with a maximum transmission loss of 7dB, would have a full width half maximum spectral bandwidth of more than 5nm. Hence an array of ten such linear gratings would have a spectral bandwidth of more than 50nm. Use of, for example, the 10 pass band Moiré grating therefore reduces the required operating spectral bandwidth by more than 40nm.

The sensor length can be considered to be very short. Because the nulls in the refractive index profile define the pass band, this allows quasi-point measurements to be made and thus provides for high spatial resolution measurements. This short sensor length also enables a large number of measurements, of for example strain or temperature, to be taken over a small distance, such as 5-20mm, and within a single grating structure. Thus a greater spatial and spectral resolution is provided than for an equivalent number of discrete linear fibre Bragg gratings. Both linear and non-linear gradients of a chosen measurand can be measured.

Various modifications can be made without departing from the scope of the invention. For example, the grating portion may be a different type of grating to that described, and may be fabricated in a single step, for instance by using a known phase-mask fabrication method or a known side-etched surface-relief grating fabrication method. Using the phase-mask fabrication method, the grating portion structure may be represented on a phase-mask and directly inscribed in the fibre through the phase-mask. Alternatively, the grating

portion may be inscribed in the fibre through a phase-mask, the phase-mask and/or the fibre being oscillated along their longitudinal direction during fabrication to thereby control the refractive index profile within the grating portion.

The Moiré gratings can be formed as two superimposed Bragg gratings of different central wavelength or chirp. Two gratings which vary slightly in bandwidth and/or central wavelength and/or chirp rate and/or the amount of physical overlap between the gratings will give rise to periodic nulls when superimposed, and are thus likely to be of use in sensing applications. Alternatively, the profile of the Moiré grating could be devised to provide a plurality of nulls, without necessarily being reproducible by superimposing two gratings. Thus, the invention extends beyond the use of Moiré gratings, which would conventionally be considered to be the result of the superimposition of two grating structures. The grating structure may also be a single linear or chirped fibre Bragg grating in which parts of the grating are amplitude masked out during fabrication or are erased by further exposing sections of the grating following fabrication.

It will be appreciated that the grating structure may be fabricated in many different types of photosensitive enhanced optical fibre, other than that described, including Boron-germania co-doped fibre, and hydrogen loaded standard fibre. It will also be appreciated that the grating structures can be fabricated at a wide range of different central wavelengths, to suit a particular optical source and optical detector. This will to some extent affect which type of fibre the grating structure is fabricated in.

Grating portions of different length, bandwidth and number of pass bands may be used. More than one grating portion may be provided within a fibre grating sensor.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should

be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation having an amplitude envelope which includes at least one region in which the amplitude of the envelope is substantially reduced, the said variation giving the grating portion a spectral profile within which there is at least one pass band.
2. A sensor according to claim 1 in which the amplitude envelope includes a plurality of regions in which the amplitude of the envelope is substantially reduced.
3. A sensor according to claim 2 in which the amplitude envelope includes a plurality of regions in which the amplitude of the envelope is substantially nulled.
4. A sensor according to claim 2 or 3 in which the periodic variation in the or each region includes a section in which the phase of the periodic variation substantially reverses.
5. A sensor according to any of claims 2 to 4 in which adjacent regions are spatially separated.
6. A sensor according to any preceding claim in which the or each region gives rise to a corresponding pass band.
7. A sensor according to claim 6 in which each region is an independently actuatable sensor element operable to vary the wavelength of the corresponding pass band in response to a change in a parameter being measured.
8. A sensor according to any preceding claim in which the grating portion comprises two substantially superimposed fibre Bragg gratings.

9. A sensor according to claim 8 in which the amplitudes of the refractive index profiles of the two gratings add together to form the amplitude envelope.
10. A sensor according to claim 8 or 9 in which the fibre Bragg gratings are chirped fibre Bragg gratings.
11. A sensor according to claim 10 in which the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the second chirped grating.
12. A sensor according to claim 10 in which the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.
13. A sensor according to claim 8 or 9 in which the fibre Bragg gratings are linear fibre Bragg gratings.
14. A sensor according to claim 13 in which the two linear gratings have substantially the same spectral bandwidth.
15. A sensor according to claim 14 in which the first linear grating has a different central wavelength to the second linear grating.
16. A sensor according to any of claims 1 to 7 in which the grating portion comprises one fibre Bragg grating having a plurality of regions within which the refractive index profile of the grating is substantially reduced or nulled.
17. A sensor according to claim 16 in which the fibre Bragg grating is a linear grating or a chirped grating.
18. A sensor according to any of claims 8 to 17 in which the or each fibre Bragg grating is fabricated using a two-beam interference holographic

fabrication method.

19. A sensor according to any of claims 8 to 17 in which the or each fibre Bragg grating is fabricated using a phase-mask fabrication method.

20. A sensor according to claim 18 when dependent on claim 16 or 17 in which the or each region in the fibre Bragg grating is formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method by providing an amplitude mask generally in front of the fibre, generally in the beam paths, during fabrication.

21. A sensor according to claim 18 or 19 when dependent on claim 16 or 17 in which the or each region in the fibre Bragg grating is formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method or the phase-mask fabrication method by subsequently further exposing regions of the grating.

22. A sensor according to any of claims 1 to 7 in which the grating portion comprises a single grating structure fabricated using a phase-mask fabrication method.

23. A sensor according to claim 22 in which the desired grating structure is represented on a phase-mask and subsequently inscribed into the fibre through the phase-mask.

24. A sensor according to claim 22 in which the grating structure is inscribed in the fibre through a phase-mask while the fibre undergoes oscillating motion along its longitudinal direction, relative to the phase-mask, to thereby control the refractive index profile within the grating structure.

25. A fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation including at least one section in which the phase of the

periodic variation substantially reverses, the said variation giving the grating portion a spectral profile within which there is at least one pass band.

26. A sensor according to claim 25 in which the grating portion includes a plurality of sections in which the phase of the periodic variation substantially reverses.

27. A sensor according to claim 26 in which adjacent phase reversal sections are spatially separated.

28. A sensor according to any of claims 25 to 27 in which the or each phase reversal section gives rise to a corresponding pass band.

29. A sensor according to claim 28 in which each section is an independently actuatable sensor element operable to vary the wavelength of the corresponding pass band in response to a change in a parameter being measured.

30. A sensor according to any of claims 25 to 29 in which the period of the periodic variation changes along substantially the full length of the grating portion.

31. A sensor according to any of claims 25 to 30 in which the grating portion comprises two substantially overlapping chirped fibre Bragg gratings, the first chirped grating being spatially shifted relative to the second chirped grating by an integer plus a fraction of the period of the first grating.

32. A sensor according to claim 31 in which the first chirped grating is spatially shifted relative to the second chirped grating by an integer plus one half of the period of the first grating.

33. A sensor according to claim 31 or 32 in which the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the

second chirped grating.

34. A sensor according to claim 31 or 32 in which the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.

35. A sensor according to any of claims 31 to 34 in which the fibre Bragg gratings are fabricated using a known two-beam interference holographic fabrication method.

36. A sensor according to any of claims 31 to 34 in which the fibre Bragg gratings may be fabricated using a known phase-mask fabrication method.

37. A sensor according to any of claims 25 to 30 in which the grating portion comprises one chirped fibre Bragg grating having a plurality of sections in which the phase of the periodic variation substantially reverses.

38. A sensor according to claim 37 in which the single chirped fibre Bragg grating is fabricated using a known phase-mask fabrication technique.

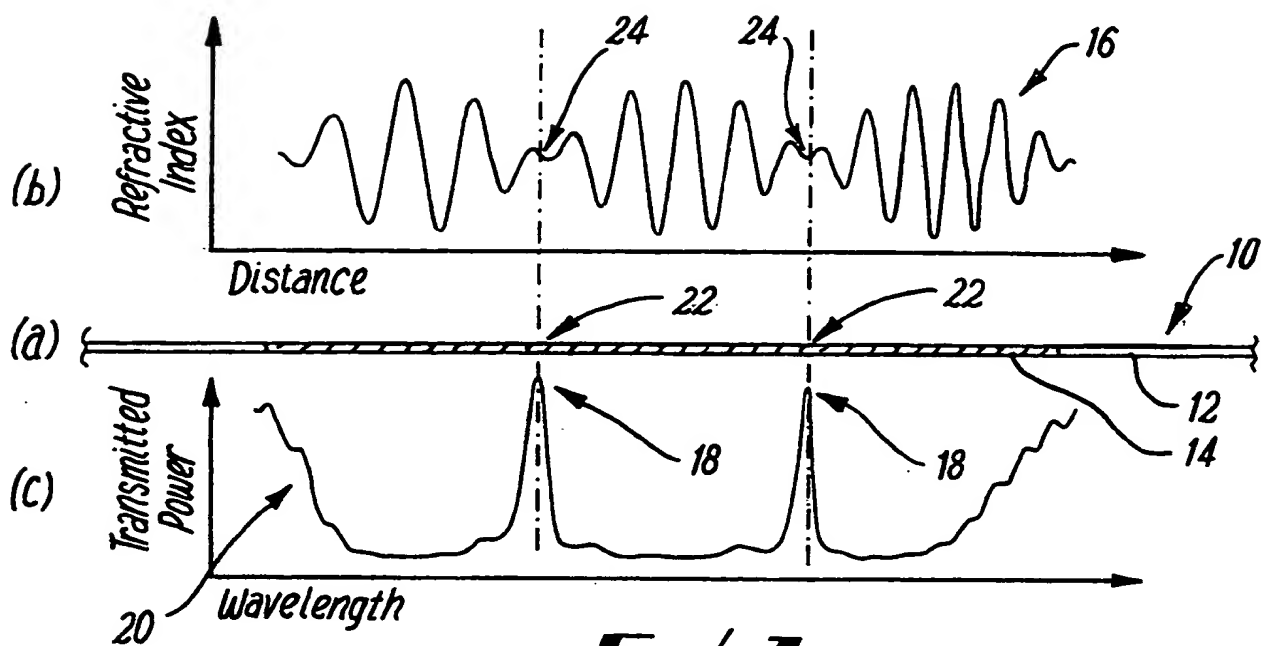
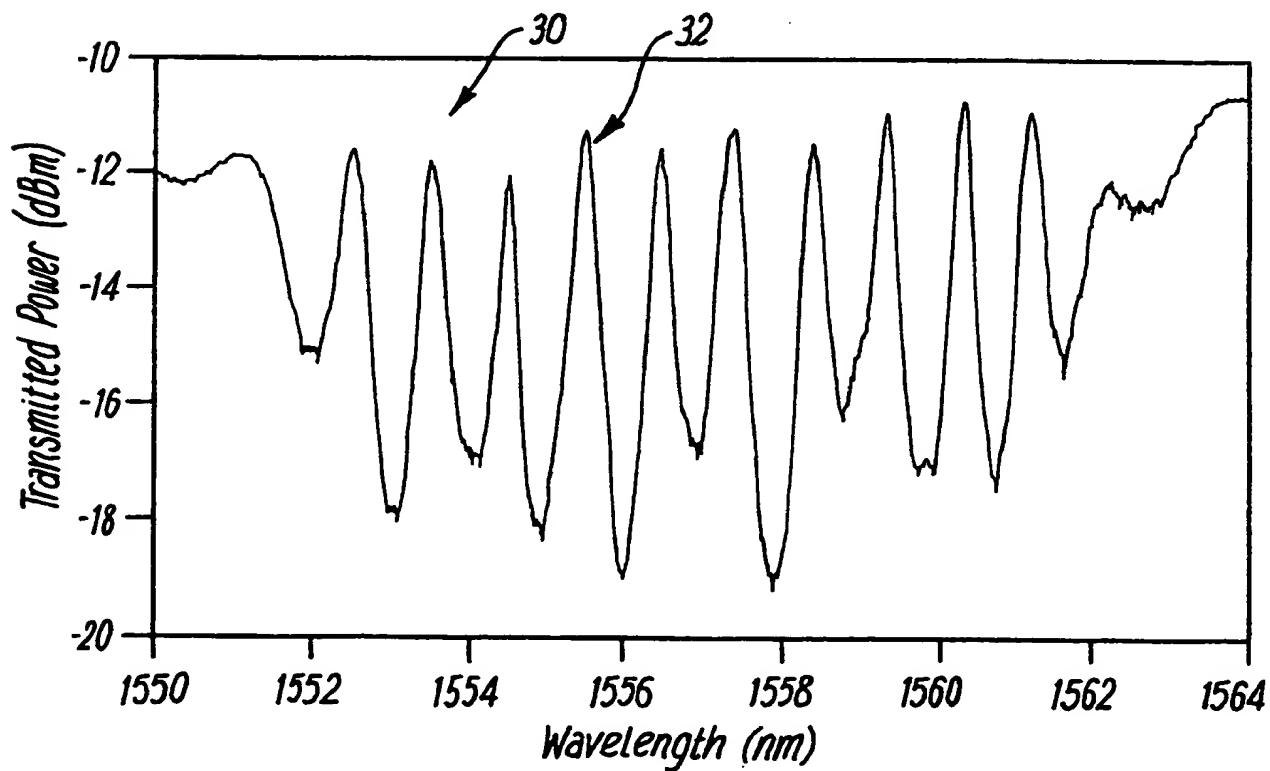
39. A sensor according to claim 38 in which a first part of the chirped grating having a first spectral bandwidth is represented on a phase-mask and subsequently inscribed into the fibre.

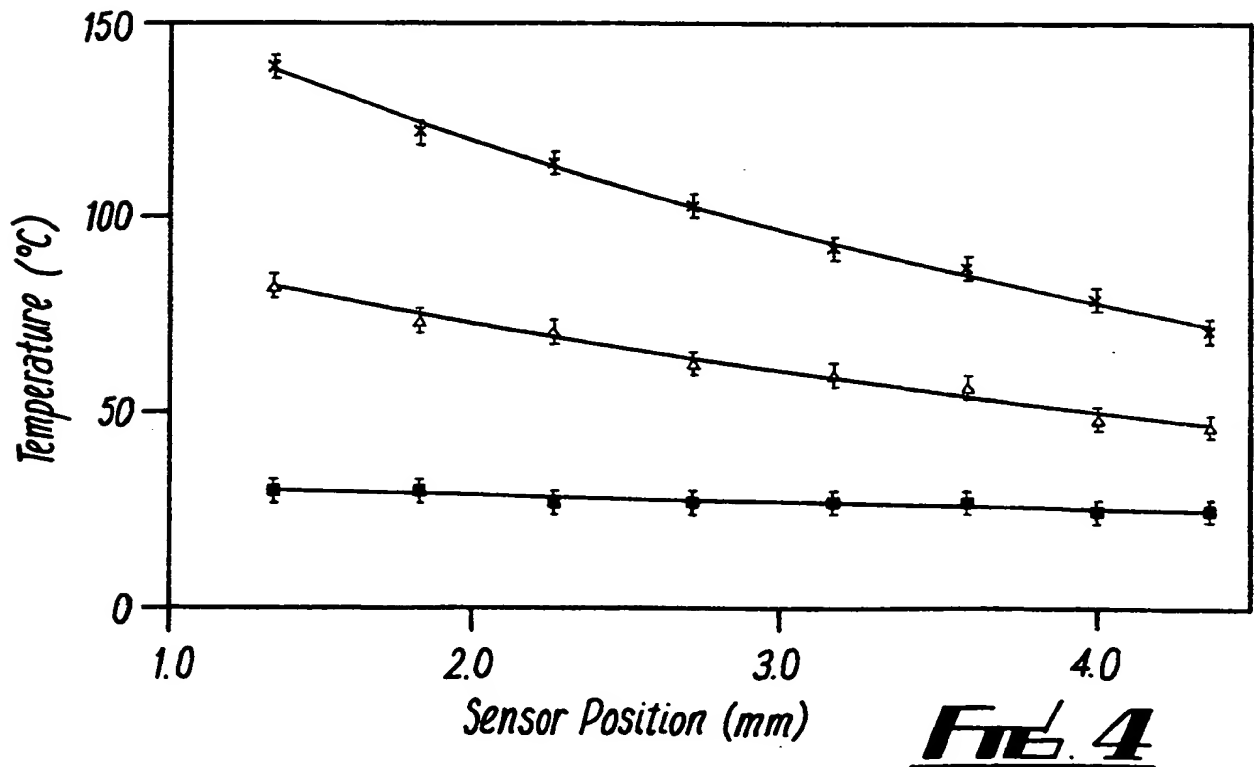
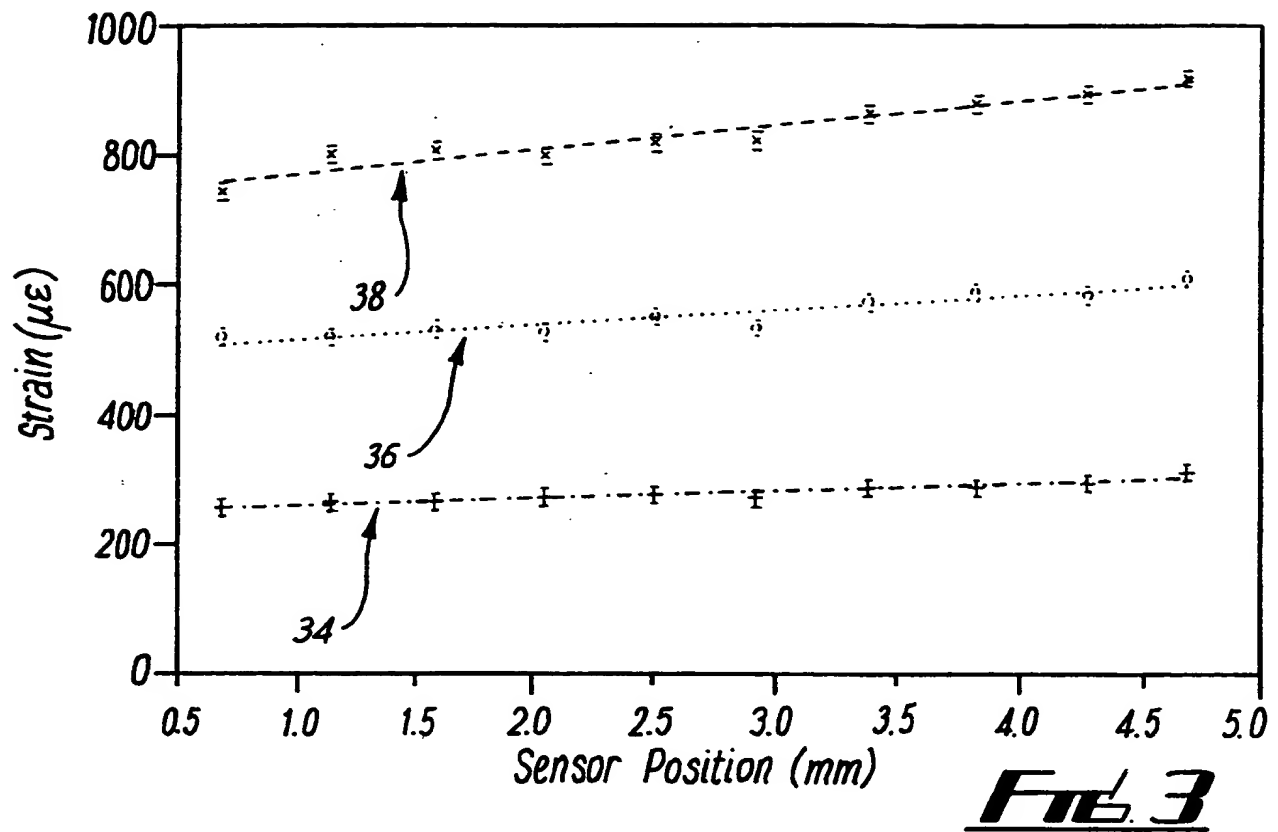
40. A sensor according to claim 39 in which a second part of the chirped grating having a second spectral bandwidth is inscribed into the fibre substantially spatially and spectrally adjacent the first part, the first and second parts together forming the chirped grating.

41. A sensor according to claim 40 in which the chirped grating comprises a plurality of such parts arranged substantially spatially and spectrally sequentially adjacent one another.

42. A sensor according to any of claims 39 to 41 in which the fibre is under a first strain during inscription of the first part.
43. A sensor according to claim 42 in which the fibre is under a second strain during subscription of the second part, the first and second strains being different.
44. A sensor according to claim 37 in which the chirped grating is fabricated using a single phase-mask, the desired structure of the chirped grating being represented on the phase-mask and subsequently inscribed into the fibre through the phase-mask.
45. A sensor according to claim 37 in which the chirped grating is fabricated using a known continuous writing technique.
46. A sensor according to any preceding claim in which the optical fibre is photosensitive enhanced optical fibre.
47. A sensor according to claim 46 in which the photosensitive enhanced optical fibre is germania doped optical fibre, or boron-germania co-doped optical fibre.
48. A sensor according to claim 46 or 47 in which the fibre is hydrogen loaded to increase the photosensitivity of the fibre.
49. A sensor according to claim 48 in which the hydrogen loaded fibre is annealed following fabrication of the grating structure to substantially remove any residual hydrogen from the fibre.
50. A sensor according to any of claims 1 to 7 and 25 to 30 in which the grating portion comprises a surface-relief grating structure side-etched in an optical fibre.

51. A sensor according to any preceding claim in which the fibre grating sensor comprises a plurality of grating portions.
52. A fibre optic grating sensor substantially as described above with reference to the accompanying drawings.
53. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.

**FIG. 1****FIG. 2**



INTERNATIONAL SEARCH REPORT

Int. Application No

PCT/GB 00/00566

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01L1/24 G02B6/34 G01B11/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01L G02B G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 24079 A (THE UNIVERSITY OF SIDNEY) 8 August 1996 (1996-08-08) page 1, line 29 -page 2, line 2; figures 1-9 page 4, line 2 - line 36	1-3,5, 16,17, 19,22,23
A	EP 0 893 712 A (SUMITOMO ELECTRIC INDUSTRIES LTD.) 27 January 1999 (1999-01-27) page 5, line 21 - line 56; figures 20A,20B,21	1,25
A	US 5 706 079 A (KERSEY) 6 January 1998 (1998-01-06) claim 1; figures 2,3 -/-	1,25



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"Z" document member of the same patent family

Date of the actual completion of the international search

13 April 2000

Date of mailing of the international search report

20/04/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Mucs, A

INTERNATIONAL SEARCH REPORT

Int. Application No

PCT/GB 00/00566

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 897 124 A (PHOTONICS RESEARCH ONTARIO) 17 February 1999 (1999-02-17) summary</p>	1-53

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. Application No

PCT/GB 00/00566

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9624079 A	08-08-1996	AU 693641 B AU 4531796 A CA 2211834 A EP 0807271 A JP 11500539 T	02-07-1998 21-08-1996 08-08-1996 19-11-1997 12-01-1999
EP 893712 A	27-01-1999	JP 11095033 A US 6021242 A	09-04-1999 01-02-2000
US 5706079 A	06-01-1998	NONE	
EP 897124 A	17-02-1999	JP 11174245 A	02-07-1999



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁷ : G01L 1/24, G02B 6/34, G01B 11/16	A1	(11) International Publication Number: WO 00/49378 (43) International Publication Date: 24 August 2000 (24.08.00)
---	----	--

(21) International Application Number: PCT/GB00/00566

(22) International Filing Date: 17 February 2000 (17.02.00)

(30) Priority Data:
9903597.4 18 February 1999 (18.02.99) GB(71) Applicant (for all designated States except US): OXFORD
FIBER OPTIC TOOLS LIMITED [GB/GB]; Aston Science
Park, Love Lane, Birmingham B7 4BJ (GB).

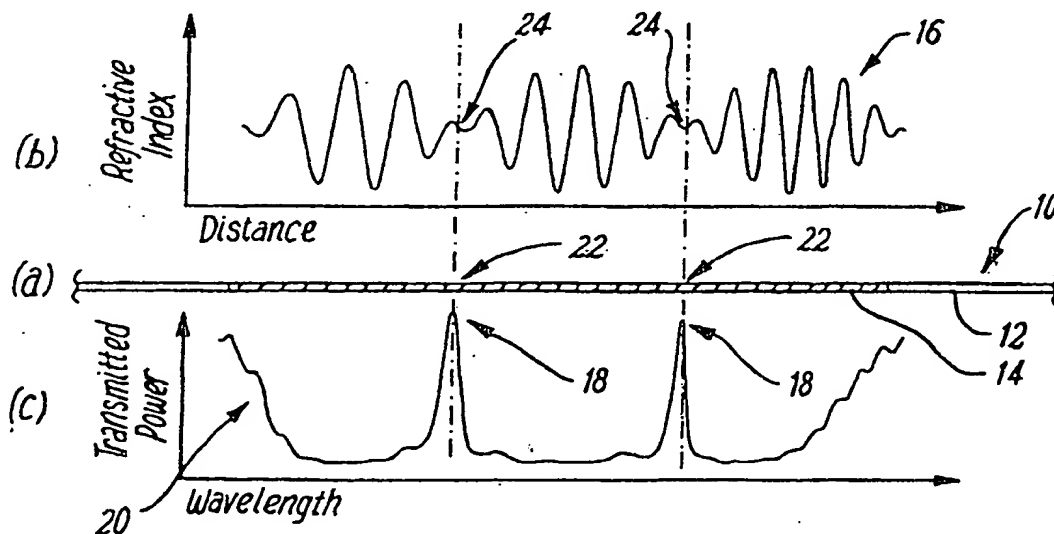
(72) Inventors; and

(75) Inventors/Applicants (for US only): SUGDEN, Catherine,
Anne [GB/GB]; Oxford Fiber Optic Tools, Aston Science
Park, Love Lane, Birmingham B7 4BJ (GB). CHISHOLM,
Karen, Elizabeth [GB/GB]; Oxford Fiber Optic Tools
Limited, Aston Science Park, Love Lane, Birmingham B7
4BJ (GB). ZHANG, Lin [CN/GB]; Electronic Engineering,
Aston University, Aston Triangle, Birmingham B4 7ET
(GB).(74) Agent: SKINNER, Michael, Paul; Swindell & Pearson, 48 Friar
Gate, Derby DE1 1GY (GB).(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG,
BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE,
ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP,
KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA,
MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU,
SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG,
US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE,
LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM,
AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT,
BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU,
MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM,
GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

With international search report.

(54) Title: FIBRE OPTIC GRATING SENSOR



(57) Abstract

A fibre optic grating sensor (10) comprising an optical fibre (12) in which a grating portion (14) is provided, the refractive index (16) of the fibre (12) varying periodically along the grating portion (14). The periodic variation of the refractive index (16) has an amplitude envelope which includes, in this example, two regions (24) in which the amplitude of the envelope is substantially reduced, and in this example is substantially nulled. The null regions (24) give the grating portion a spectral profile (20) within which there are, in this example, two pass bands (18).

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 00/00566

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01L1/24 G02B6/34 G01B11/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01L G02B G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 24079 A (THE UNIVERSITY OF SIDNEY) 8 August 1996 (1996-08-08) page 1, line 29 - page 2, line 2; figures 1-9 page 4, line 2 - line 36	1-3, 5, 16, 17, 19, 22, 23
A	EP 0 893 712 A (SUMITOMO ELECTRIC INDUSTRIES LTD.) 27 January 1999 (1999-01-27) page 5, line 21 - line 56; figures 20A, 20B, 21	1, 25
A	US 5 706 079 A (KERSEY) 6 January 1998 (1998-01-06) claim 1; figures 2, 3	1, 25

-/-

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

G document member of the same patent family

Date of the actual completion of the international search

13 April 2000

Date of mailing of the international search report

20/04/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Mucs, A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/00566

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 9624079	A	08-08-1996	AU 693641 B AU 4531796 A CA 2211834 A EP 0807271 A JP 11500539 T	02-07-1998 21-08-1996 08-08-1996 19-11-1997 12-01-1999
EP 893712	A	27-01-1999	JP 11095033 A US 6021242 A	09-04-1999 01-02-2000
US 5706079	A	06-01-1998	NONE	
EP 897124	A	17-02-1999	JP 11174245 A	02-07-1999

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/00566

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 897 124 A (PHOTONICS RESEARCH ONTARIO) 17 February 1999 (1999-02-17) summary</p>	1-53

2 / PATS

Fibre Optic Grating Sensor

This invention relates to a fibre optic grating sensor, particularly but not exclusively a fibre optic grating strain or temperature sensor.

It is known that fibre Bragg gratings may be used as a tool for measuring, for example, temperature and strain. The grating is formed in the fibre to reflect light at a wavelength which is determined by the physical characteristics of the grating. A change in the temperature and/or strain applied to a fibre Bragg grating changes the period of the grating and hence the wavelength of the light reflected by the grating. Arrays of fibre Bragg gratings, in which the gratings are spatially separated along a length of fibre and the spectral profiles of the gratings are separated in wavelength, have been used to measure strain and temperature gradients by illuminating the array with broadband light and measuring the wavelength of the reflected light. A measurement of the wavelength shift (if any) provided by each grating provides information about the strain or temperature at that grating. Using a grating array to make a quasi-distributed strain or temperature measurement along a short length (about 5cm or less) requires the fabrication of grating arrays comprising gratings of very short spatial length (generally less than 4mm). For short length arrays, the spatial separation between adjacent gratings often becomes comparable to the spatial length of the gratings. In order to increase the number of gratings within the array the length of the gratings must be decreased, which rapidly increases the spectral bandwidth of the grating and hence reduces the spectral resolution of the sensor.

It is an object of the present invention to provide an improved fibre optic grating sensor.

According to one aspect of the present invention there is provided a fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation having an amplitude envelope which includes at least one region in which the

According to a further aspect of the present invention there is provided a fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation including at least one section in which the phase of the periodic variation substantially reverses, the said variation giving the grating portion a spectral profile within which there is at least one pass band.

The grating portion preferably includes a plurality of sections in which the phase of the periodic variation substantially reverses. The or each phase reversal section desirably gives rise to a corresponding pass band. Adjacent phase reversal sections, and hence adjacent sensors, are desirably spatially separated. Preferably each sensor is independently actuatable and hence the wavelengths of the corresponding pass bands are independently variable.

Preferably, the period of the periodic variation changes along at least part of the grating portion, and most preferably changes along substantially the full length of the grating portion.

The grating portion preferably comprises two substantially overlapping chirped fibre Bragg gratings, the first chirped grating being spatially shifted relative to the second chirped grating by an integer plus a fraction of the period of the first grating. The first chirped grating is preferably spatially shifted relative to the second chirped grating by an integer plus one half of the period of the first grating.

Desirably, the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the second chirped grating. Alternatively, the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.

portion may be inscribed in the fibre through a phase-mask, the phase-mask and/or the fibre being oscillated along their longitudinal direction during fabrication to thereby control the refractive index profile within the grating portion.

The Moiré gratings can be formed as two superimposed Bragg gratings of different central wavelength or chirp. Two gratings which vary slightly in bandwidth and/or central wavelength and/or chirp rate and/or the amount of physical overlap between the gratings will give rise to periodic nulls when superimposed, and are thus likely to be of use in sensing applications. Alternatively, the profile of the Moiré grating could be devised to provide a plurality of nulls, without necessarily being reproducible by superimposing two gratings. Thus, the invention extends beyond the use of Moiré gratings, which would conventionally be considered to be the result of the superimposition of two grating structures. The grating structure may also be a single linear or chirped fibre Bragg grating in which parts of the grating are amplitude masked out during fabrication or are erased by further exposing sections of the grating following fabrication.

It will be appreciated that the grating structure may be fabricated in many different types of photosensitive enhanced optical fibre, other than that described, including Boron-germania co-doped fibre, and hydrogen loaded standard fibre. It will also be appreciated that the grating structures can be fabricated at a wide range of different central wavelengths, to suit a particular optical source and optical detector. This will to some extent affect which type of fibre the grating structure is fabricated in.

Grating portions of different length, bandwidth and number of pass bands may be used. More than one grating portion may be provided within a fibre grating sensor.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should

be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation having an amplitude envelope which includes at least one region in which the amplitude of the envelope is substantially reduced, the said variation giving the grating portion a spectral profile within which there is at least one pass band.
2. A sensor according to claim 1 in which the amplitude envelope includes a plurality of regions in which the amplitude of the envelope is substantially reduced.
3. A sensor according to claim 2 in which the amplitude envelope includes a plurality of regions in which the amplitude of the envelope is substantially nulled.
4. A sensor according to claim 2 or 3 in which the periodic variation in the or each region includes a section in which the phase of the periodic variation substantially reverses.
5. A sensor according to any of claims 2 to 4 in which adjacent regions are spatially separated.
6. A sensor according to any preceding claim in which the or each region gives rise to a corresponding pass band.
7. A sensor according to claim 6 in which each region is an independently actuatable sensor element operable to vary the wavelength of the corresponding pass band in response to a change in a parameter being measured.
8. A sensor according to any preceding claim in which the grating portion comprises two substantially superimposed fibre Bragg gratings.

9. A sensor according to claim 8 in which the amplitudes of the refractive index profiles of the two gratings add together to form the amplitude envelope.
10. A sensor according to claim 8 or 9 in which the fibre Bragg gratings are chirped fibre Bragg gratings.
11. A sensor according to claim 10 in which the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the second chirped grating.
12. A sensor according to claim 10 in which the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.
13. A sensor according to claim 8 or 9 in which the fibre Bragg gratings are linear fibre Bragg gratings.
14. A sensor according to claim 13 in which the two linear gratings have substantially the same spectral bandwidth.
15. A sensor according to claim 14 in which the first linear grating has a different central wavelength to the second linear grating.
16. A sensor according to any of claims 1 to 7 in which the grating portion comprises one fibre Bragg grating having a plurality of regions within which the refractive index profile of the grating is substantially reduced or nulled.
17. A sensor according to claim 16 in which the fibre Bragg grating is a linear grating or a chirped grating.
18. A sensor according to any of claims 8 to 17 in which the or each fibre Bragg grating is fabricated using a two-beam interference holographic

fabrication method.

19. A sensor according to any of claims 8 to 17 in which the or each fibre Bragg grating is fabricated using a phase-mask fabrication method.
20. A sensor according to claim 18 when dependent on claim 16 or 17 in which the or each region in the fibre Bragg grating is formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method by providing an amplitude mask generally in front of the fibre, generally in the beam paths, during fabrication.
21. A sensor according to claim 18 or 19 when dependent on claim 16 or 17 in which the or each region in the fibre Bragg grating is formed in a fibre Bragg grating fabricated using the two-beam interference holographic fabrication method or the phase-mask fabrication method by subsequently further exposing regions of the grating.
22. A sensor according to any of claims 1 to 7 in which the grating portion comprises a single grating structure fabricated using a phase-mask fabrication method.
23. A sensor according to claim 22 in which the desired grating structure is represented on a phase-mask and subsequently inscribed into the fibre through the phase-mask.
24. A sensor according to claim 22 in which the grating structure is inscribed in the fibre through a phase-mask while the fibre undergoes oscillating motion along its longitudinal direction, relative to the phase-mask, to thereby control the refractive index profile within the grating structure.
25. A fibre optic grating sensor comprising an optical fibre having a grating portion along which the refractive index of the fibre varies periodically, the periodic variation including at least one section in which the phase of the

periodic variation substantially reverses, the said variation giving the grating portion a spectral profile within which there is at least one pass band.

26. A sensor according to claim 25 in which the grating portion includes a plurality of sections in which the phase of the periodic variation substantially reverses.

27. A sensor according to claim 26 in which adjacent phase reversal sections are spatially separated.

28. A sensor according to any of claims 25 to 27 in which the or each phase reversal section gives rise to a corresponding pass band.

29. A sensor according to claim 28 in which each section is an independently actuatable sensor element operable to vary the wavelength of the corresponding pass band in response to a change in a parameter being measured.

30. A sensor according to any of claims 25 to 29 in which the period of the periodic variation changes along substantially the full length of the grating portion.

31. A sensor according to any of claims 25 to 30 in which the grating portion comprises two substantially overlapping chirped fibre Bragg gratings, the first chirped grating being spatially shifted relative to the second chirped grating by an integer plus a fraction of the period of the first grating.

32. A sensor according to claim 31 in which the first chirped grating is spatially shifted relative to the second chirped grating by an integer plus one half of the period of the first grating.

33. A sensor according to claim 31 or 32 in which the two chirped gratings have substantially the same rate of chirp and substantially the same spectral bandwidth, the first chirped grating having a different central wavelength to the

second chirped grating.

34. A sensor according to claim 31 or 32 in which the first chirped grating has a different rate of chirp to the second chirped grating, and the two chirped gratings have substantially the same central wavelength and bandwidth.
35. A sensor according to any of claims 31 to 34 in which the fibre Bragg gratings are fabricated using a known two-beam interference holographic fabrication method.
36. A sensor according to any of claims 31 to 34 in which the fibre Bragg gratings may be fabricated using a known phase-mask fabrication method.
37. A sensor according to any of claims 25 to 30 in which the grating portion comprises one chirped fibre Bragg grating having a plurality of sections in which the phase of the periodic variation substantially reverses.
38. A sensor according to claim 37 in which the single chirped fibre Bragg grating is fabricated using a known phase-mask fabrication technique.
39. A sensor according to claim 38 in which a first part of the chirped grating having a first spectral bandwidth is represented on a phase-mask and subsequently inscribed into the fibre.
40. A sensor according to claim 39 in which a second part of the chirped grating having a second spectral bandwidth is inscribed into the fibre substantially spatially and spectrally adjacent the first part, the first and second parts together forming the chirped grating.
41. A sensor according to claim 40 in which the chirped grating comprises a plurality of such parts arranged substantially spatially and spectrally sequentially adjacent one another.

42. A sensor according to any of claims 39 to 41 in which the fibre is under a first strain during inscription of the first part.
43. A sensor according to claim 42 in which the fibre is under a second strain during subscription of the second part, the first and second strains being different.
44. A sensor according to claim 37 in which the chirped grating is fabricated using a single phase-mask, the desired structure of the chirped grating being represented on the phase-mask and subsequently inscribed into the fibre through the phase-mask.
45. A sensor according to claim 37 in which the chirped grating is fabricated using a known continuous writing technique.
46. A sensor according to any preceding claim in which the optical fibre is photosensitive enhanced optical fibre.
47. A sensor according to claim 46 in which the photosensitive enhanced optical fibre is germania doped optical fibre, or boron-germania co-doped optical fibre.
48. A sensor according to claim 46 or 47 in which the fibre is hydrogen loaded to increase the photosensitivity of the fibre.
49. A sensor according to claim 48 in which the hydrogen loaded fibre is annealed following fabrication of the grating structure to substantially remove any residual hydrogen from the fibre.
50. A sensor according to any of claims 1 to 7 and 25 to 30 in which the grating portion comprises a surface-relief grating structure side-etched in an optical fibre.

51. A sensor according to any preceding claim in which the fibre grating sensor comprises a plurality of grating portions.
52. A fibre optic grating sensor substantially as described above with reference to the accompanying drawings.
53. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.